GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. A-3762 GTRI/~~GIT~~ DATE 2 /22 /84

Project Director: Vic Tripp ~~School~~/Lab ECSL/EED

Sponsor: Hayes International Corporation

Type Agreement: Purchase Order No. 909623

Award Period: From 2/9/84 To 4/9/84 (Performance) 5/9/84 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$ 5,000	$ 5,000
Funded:	$ 5,000	$ 5,000

Cost Sharing Amount: $ ______ Cost Sharing No: ______

Title: Analysis of Tow-Target Cable Antenna

ADMINISTRATIVE DATA

OCA Contact Brian J. Lindberg x-4820

1) Sponsor Technical Contact:

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Hayes International Corporation
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Defense Priority Rating: N/A

Military Security Classification: N/A

(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Sponsor; however none proposed.

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date June 6, 1984

Project No. A-3762

~~School~~/Lab ECSL/EED

Includes Subproject No.(s)

Project Director(s) Vic Tripp GTRI / ~~GIT~~

Sponsor Hayes International Corporation

Title Analysis Of Tow-Target Cable Antenna

Effective Completion Date: 4/9/84 (Performance) 5/9/84 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
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- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
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ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

25 April 1984

Hayes International Corp.
Targets Division
1371 Borden Avenue
Leeds, Alabama 35094

Attention: Mr. Walt Pearson

Subject: Final Letter Report for the Project Entitled "Analysis of 72.4 MHz Tow Target Antennas"

Reference: Purchase Order No. 909623

Gentlemen:

This letter report is being submitted to satisfy the requirements of the referenced purchase order. The analysis presented was performed at the Engineering Experiment Station (EES) of the Georgia Institute of Technology for Hayes International Corp. under the technical guidance of Mr. Walt Pearson. The work was performed by the Electromagnetic Effectiveness Division of the Electronics and Computer Systems Laboratory under the direction of Victor K. Tripp.

This final letter report covers the work which was performed in the period from February 9, 1984 through April 9, 1984. This research addressed the problem of occasionally insufficient signal in the 72.4 MHz command link from the Lear jet towing aircraft to the tow target. The original scope of the order was to investigate only the receiving antenna in the tow target since it appeared to be the component of poorest design; however, some analysis was also performed on the transmit antenna. The details of the analysis of the present receive configuration, alternative receive configurations, and the present transmit configuration are presented in the attachment. Conclusions and recommendations for further investigation are also discussed therein.

The author is pleased to acknowledge the support of Mr. William P. Cooke and Mr. Robert Murphy of Georgia Tech and other members of the Electromagnetic Effectiveness Division, including the Chief, Dr. Charles E. Ryan, Jr. and the secretary, Ms. Beatriz Gonzalez. Acknowledgment is also extended to Mr. Walt Pearson and Mr. Denton Marlow of Hayes for their prompt responses to my questions.

Respectfully submitted,

Victor K. Tripp
Project Director

Approved:

Charles E. Ryan, Jr.
Chief,
EM Effectiveness Division

ANALYSIS OF 72.4 MHz TOW TARGET ANTENNA

I. Analysis of Present Receive Antenna

A. Modeling

The receiving end of the command link from the towing aircraft to the tow target was selected for investigation because it was considered to be the most likely source of failure. It was suspected that the rather unconventional receive antenna configuration was producing a severe mismatch with the receiver such that very little power was transmitted to the receiver.

The tow target is illustrated in Figure 1 showing its metallic parts in solid outlines and other main features in dashed outlines. Some of the metallic parts in the tow target are used as the receiving antenna. In particular, those parts shaded with lines -- the tow cable, the reel, and the bulkheads to which it connects -- were intended to serve as the antenna. Actually, those parts shaded with hash marks will also radiate as part of the antenna.

The feed cable of the receiver is a semi-rigid coaxial cable whose center conductor is connected to one of the bulkheads to which the tow cable is connected. All of these metallic parts, which are electrically connected to the center conductor, form one side of the antenna. Although it may not be obvious, there are two sides to this antenna, as there are to any antenna. This principle can be seen by the fact that the input to the antenna is a voltage signal, and a voltage must appear between two conductors. In this case, the voltage that travels down the coaxial cable appears in the receiver between the inner conductor and the inside surface of the outer conductor of the coax. This voltage, in turn, is initiated at the point where the outer conductor stops by a voltage between the bulkhead and the outer surface of the coaxial cable. For radio frequencies, of course, the skin depth of conductors is such that currents on the outer surface must travel around the end of the outer conductor to get to the inner surface; they cannot short directly through the wall.

Thus, the other side of the receive antenna is the outer surface of the feed cable and everything that is attached to it. In this case, the

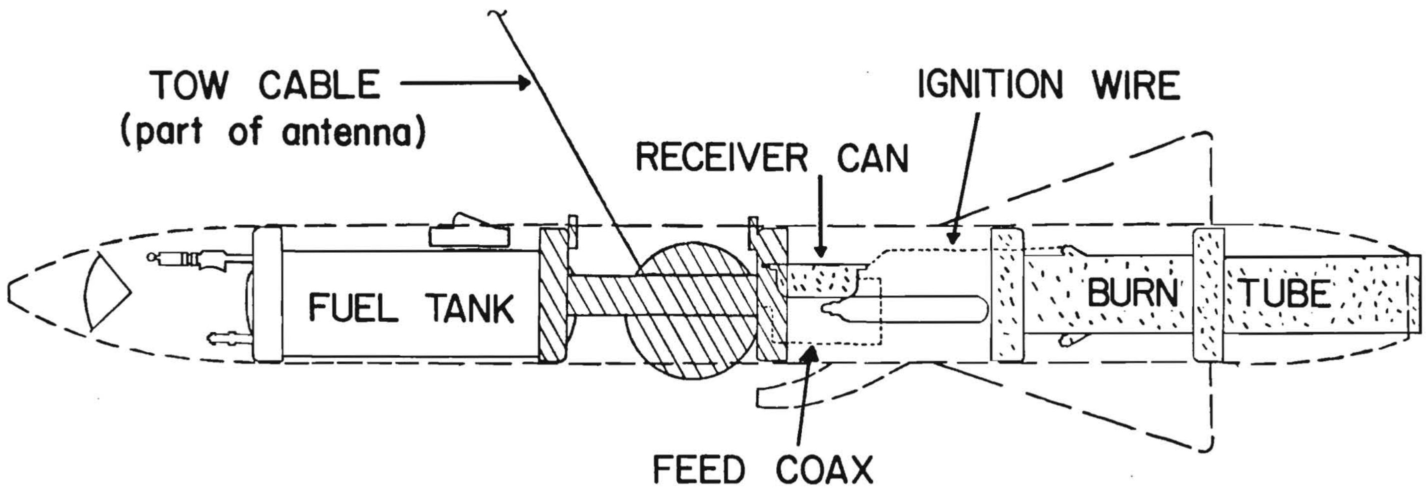


Figure 1. Illustration of the tow target and receive antenna configuration.

receiver can and the burn tube are attached. One can view the entire system as a very irregular dipole, one side of which includes the tow cable and the other side of which contains the receiver circuit inside the dipole arm. Again, these two sides of the antenna are shaded differently in Figure 1.

The frequency of 72.4 MHz produces electromagnetic waves that are 163 inches long in free space (λ = 163 inches). Since the entire tow target is only about 90 inches long, the structure is basically small compared to a wavelength and is therefore amenable to analysis by the Method of Moments. The best analytical tool for a Method of Moments analysis at this time is a thin wire computer program. This program models all parts of the structure with thin wires, between which the coupling can be evaluated. For a given set of generators and loads, the currents are evaluated on all thin wire segments by solving simultaneous linear equations. Once these currents are obtained, the useful information such as impedances and radiation patterns are easily obtained.

Although a thin wire structure often does not look very much like the structure it is intended to model, there is much experience to show that results are generally very good. In this case, some important components of the antenna are the tow cable and the coaxial feed cable; both of which can be well modeled by thin wire segments. Some bulky metallic components such as the fuel tank are not nearly as important since they are not connected to the actual antenna components. In general, there is little reason to doubt the validity of thin wire modeling for this application.

The receive antenna was modeled by the tow target model shown in Figure 2 with the addition of a long properly curved tow cable. This model contains all the significant metallic parts and probably includes some that are not significant. It contains all the bulkheads, the fuel tank, and the burn tube, which are all modeled as squares. It includes the tow cable reel and its supporting rails, the receiver can and feed cable. It also includes the pressure bottles modeled as simple dipoles. The receiver can was made pyramidal rather than rectangular to reduce computer resource requirements. (The volume of the can is much more important electrically than the number of edges it has.) This complete model without its tow cable included 63 junction points and 78 thin wire segments. The currents on the segments can be obtained by solving 107 simultaneous linear equations.

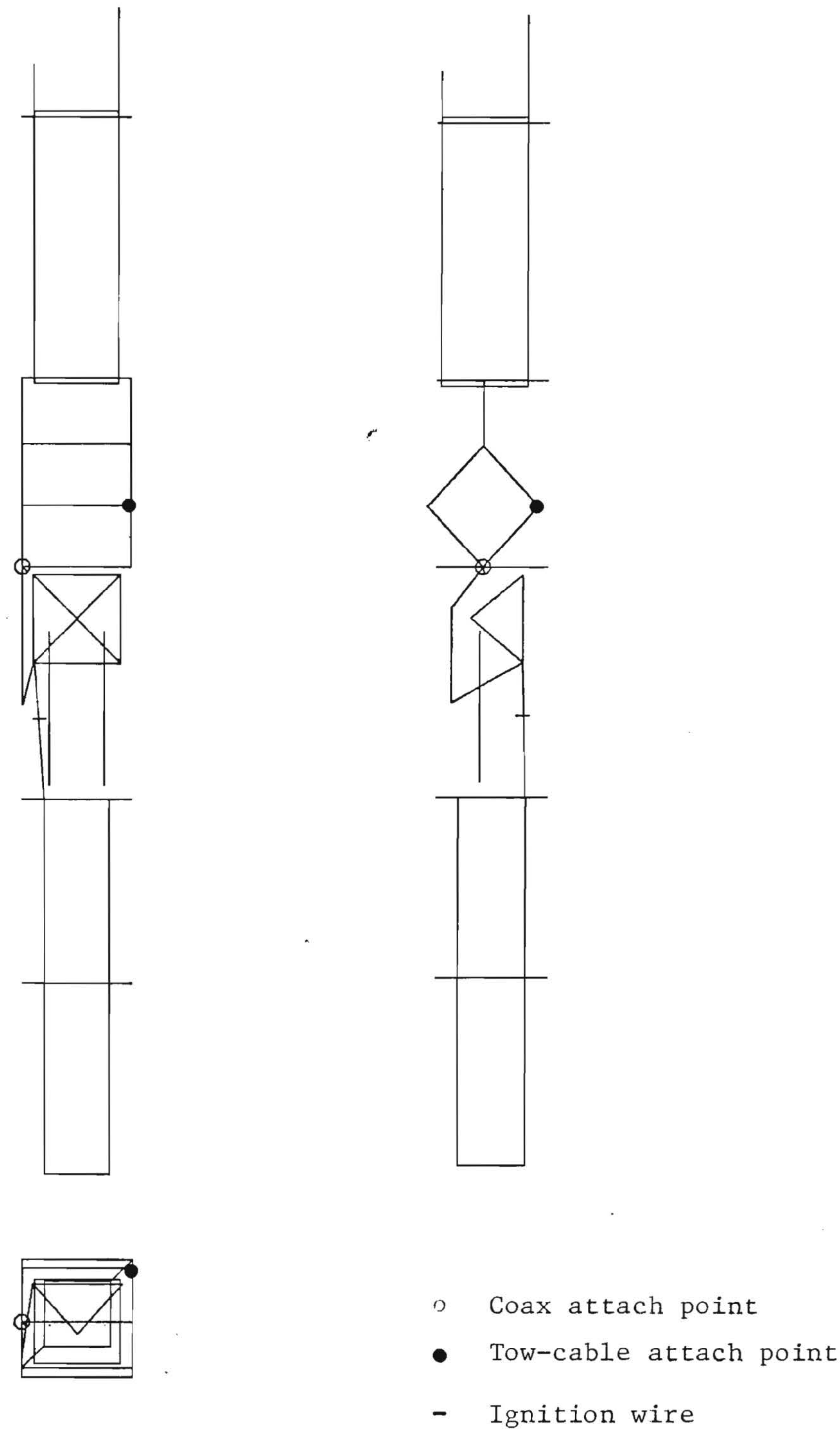


Figure 2. Model of the tow target used in the thin-wire analysis.

B. Validation

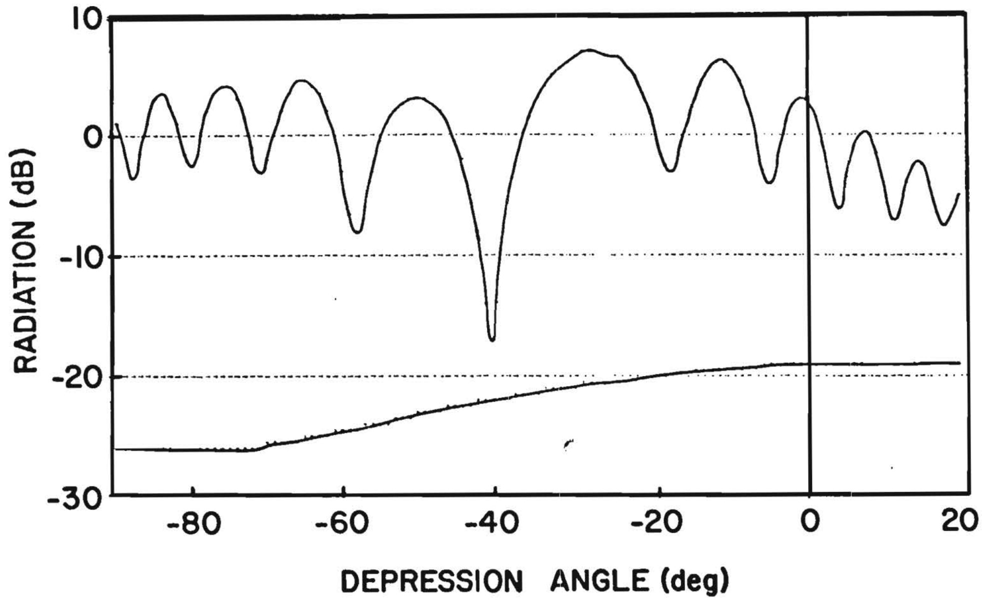
One of the rules of a valid thin wire model is that the segments must be short compared to a wavelength. Specifically, one-fourth wavelength is generally considered to be the maximum segment length. Thus, to model the entire tow cable would require about 3,700 wire segments, far too many for the capacity of modern computers. Fortunately, only the cable near the target affects the antenna performance. In order to determine how much of the tow cable must be modeled, calculations were performed for various lengths. For a sufficient length of cable, a change in that length was found to not significantly change the calculated results. That is, currents induced in the cable beyond this length did not reach the receiver and therefore did not need to be considered. This length was found to occur at about 18 to 20 wavelengths (250 feet). Figure 3 shows the significant change observed in the received pattern as the cable length is changed from 10.31λ to 10.55λ . The impedance changed from $(7.6, -63)\,\Omega$ to $(32.1, -70)\,\Omega$ (Ohms-resistive, reactive). Figure 4 illustrates the convergence observed changing the length from 18.65λ to 18.90λ . The pattern changes little in the region of interest (near 0°) and the impedance change was only from $(15.6, -67)\Omega$ to $(16.3, -50)\Omega$.

To determine whether the segment length was too long, some calculations were repeated for $\lambda/8$ tow-cable segments and compared to calculations for $\lambda/4$ segments. The results were essentially identical with the impedance and pattern levels changing by less than two percent. Clearly the increased accuracy was not significant enough to warrant using shorter segments with the resulting increase in computational cost.

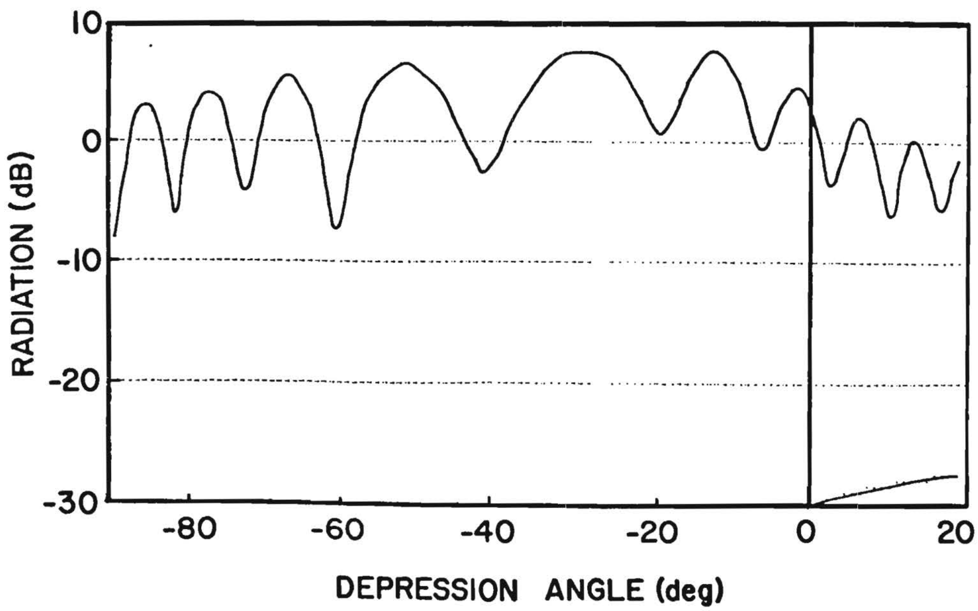
Finally, the computer program, itself, was validated. The final point of verification of the model was made by calculating the impedance for a very short dipole with a given radius and then comparing it to the value published in a book. The calculated value was $(4.8, -719)\Omega$ at the feed point. The book value was $(5.0, -713)\,\Omega$.

C. Calculations

The object of this analysis was to determine whether the receive antenna configuration was responsible for the observed signal loss. There are three possible sources of signal loss in an antenna, and they are all included in the antenna gain pattern. The first possible loss mechanism is

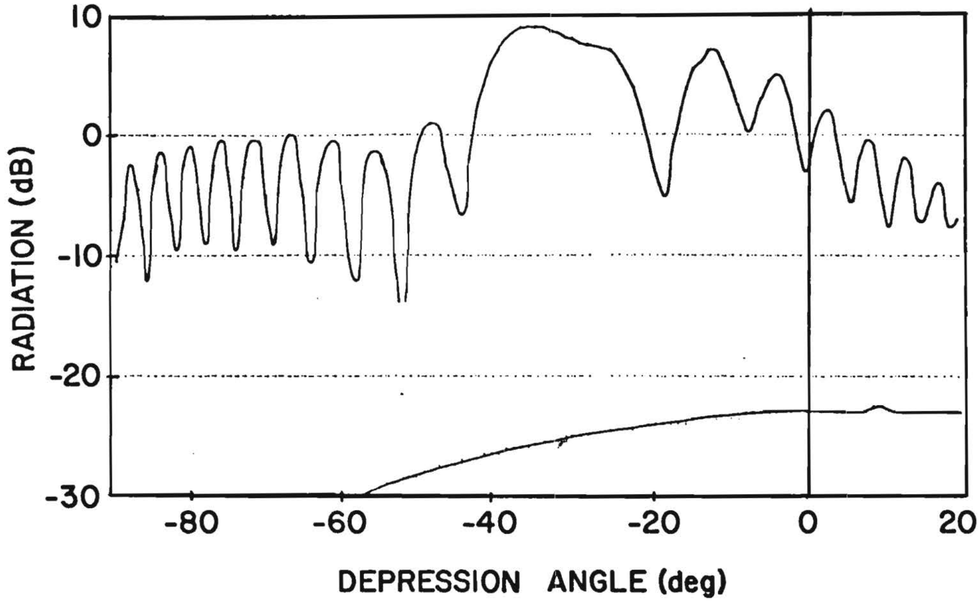


(a) Cable 1720" long

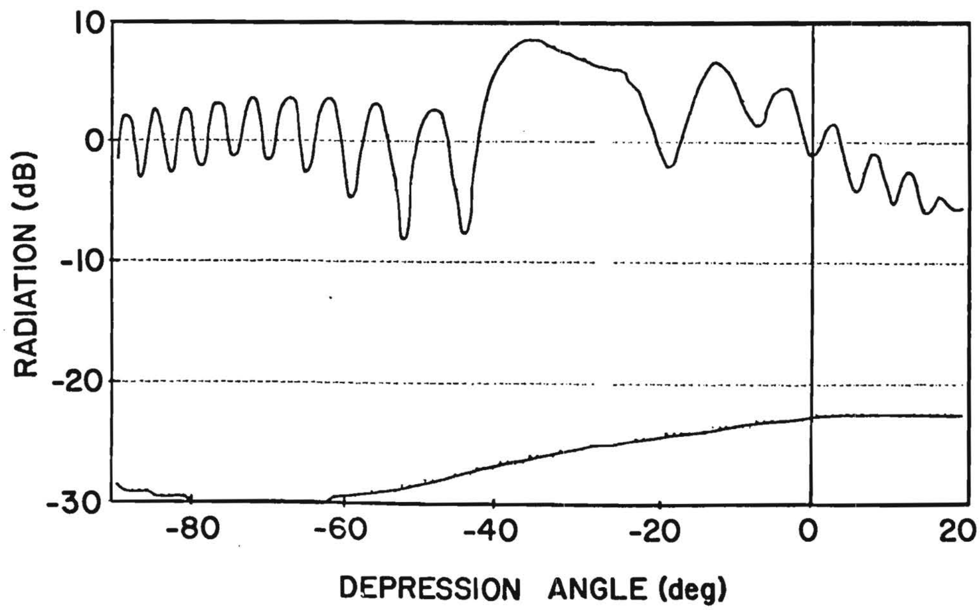


(b) Cable 1680" long

Figure 3. Comparison of patterns for different tow-cable lengths near 11λ.



(a) Cable 3080" long



(b) Cable 3040" long

Figure 4. Comparison of patterns for different tow-cable lengths near 19λ.

reflection due to an impedance mismatch at the junction between the receiver and the antenna. The second possible mechanism is low efficiency; that is, the dissipation of the signal as heat in the antenna. The third is simply that the antenna may radiate its power in directions other than the desired direction. The directivity pattern measures this effect.

The results of the thin wire model depend on the radius of the wires, although they are usually relatively insensitive to radius. There are three actual wires in the structure. One is the coaxial cable from the receiver to the feed point on the bulk head, another is the tow cable, and the other is the ignition wire. The radius of the coaxial cable is about 70 mils, that of the tow cable is about 18 mils, and the ignition wire size is unknown. Since the tow cable is stranded, its effective radius will not be exactly 18 mils. At these RF frequencies, the conductor skin depth is so shallow that the circumference of the wire is the relevant parameter rather than the cross sectional area. On the other hand, currents on the surface of the wire strands can be expected to concentrate on the outer surface of the outer strands more than at the points where the outer strands touch. Thus, it is not clear what the effective radius of a stranded wire should be, and therefore, a radius of 18 mils was used for this model. Since the radius must be the same for all segments, the radii of the coaxial cable, and the ignition wire were not used because they were not considered to be so important as the tow cable. The tow cable is much longer, and the results should be much more dependent on the tow cable radius than on the other two radii. (Experience has shown that the modeling of bulky components, like the burn tube, is not sensitive to the wire radius.)

Since antennas are generally made out of good conductors, they can often be modeled by wires with infinite conductivity. Many calculations in this investigation were performed with infinitely conducting wires. A finite conductivity was eventually introduced, however, to improve the convergence of the results with a shorter section (19λ) of tow cable. Since the currents are attenuated by the resistance of the metal as well as by radiation, the currents in imperfect conductors become negligible at a shorter distance from the receiver terminals.

The determination of the conductivity of the tow cable was not very firm. The alloy of the cable is ASTM-228 steel for which direct resistivity or conductivity data were not available. This alloy, however, is in the class of music wire, and resistivities for related alloys were found to be about 7.7×10^6 Mhos/m. That value was used.

The impedance, efficiency, and directivity patterns were calculated for several configurations. The pattern for the model representing the actual present antenna configuration is shown in Figure 5. The impedance seen by the receiver is $(255, 319)\Omega$. For a 50 ohm receiver, this would result in a large signal reflected back from the receiver. Specifically, the signal transmitted through the mismatch to the receiver would be about 6.8 dB down from the signal available. In addition, the efficiency was calculated at 88%, but this signal loss is already included in the pattern data as presented in Figure 5. The expanded scale of Figure 6 shows that the signal level at 4^o elevation (-4^o depression) is nearly 2 dBi, but one should observe that the pattern is very choppy. A change in cable angle or perhaps a model containing more of the cable could easily shift a "null" to the direction of interest. Then the received signal would be about -7 dB.

II. Alternate Configurations

The original purpose for the investigation of alternate receive antenna configurations was to obtain an impedance closer to 50 ohms at the feed point. However, the analysis of the present configuration indicated that it had a much better impedance match than had been anticipated. Specifically, the mismatch accounts for about 7 dB of signal loss. While this is a very poor impedance match relative to common engineering practices, it is not nearly poor enough to account for the observed loss of 50 to 60 dB. Therefore, the alternate configurations were analyzed for other reasons.

The alternate configuration most analyzed was a configuration without the ignition wire. The impact of the absence of that wire is that the burn tube is no longer part of the receive antenna; that is, it would not be shaded in Figure 1. The reason for the concentrated effort on this alternate configuration was that for most of the contract period the information furnished to Georgia Tech was that there was not an electrical connection from the receiver can to the burn tube. The cable length validation tests illustrated in Figures 3 and 4 were performed on this

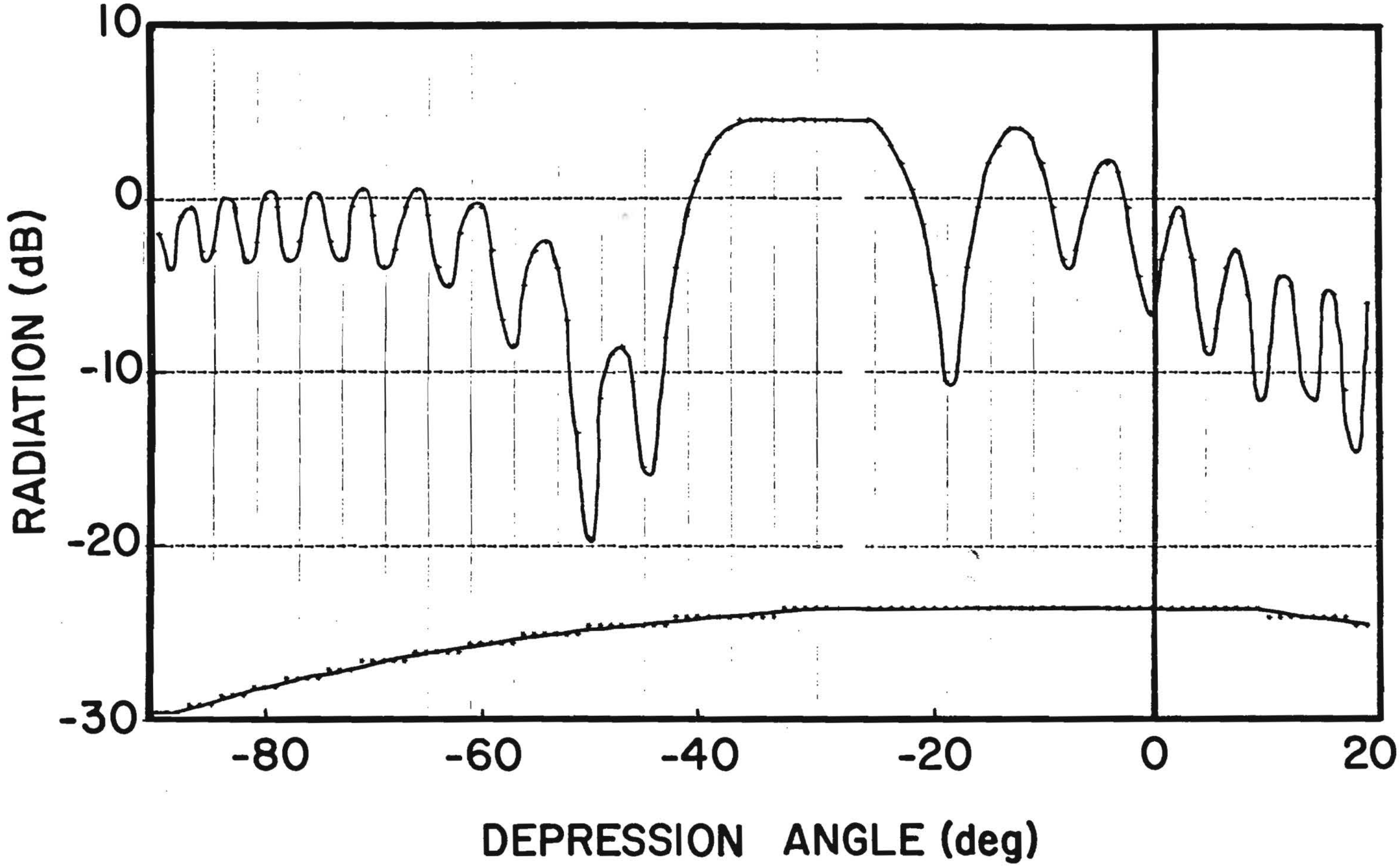


Figure 5. Radiation patterns for the present receive antenna configuration.

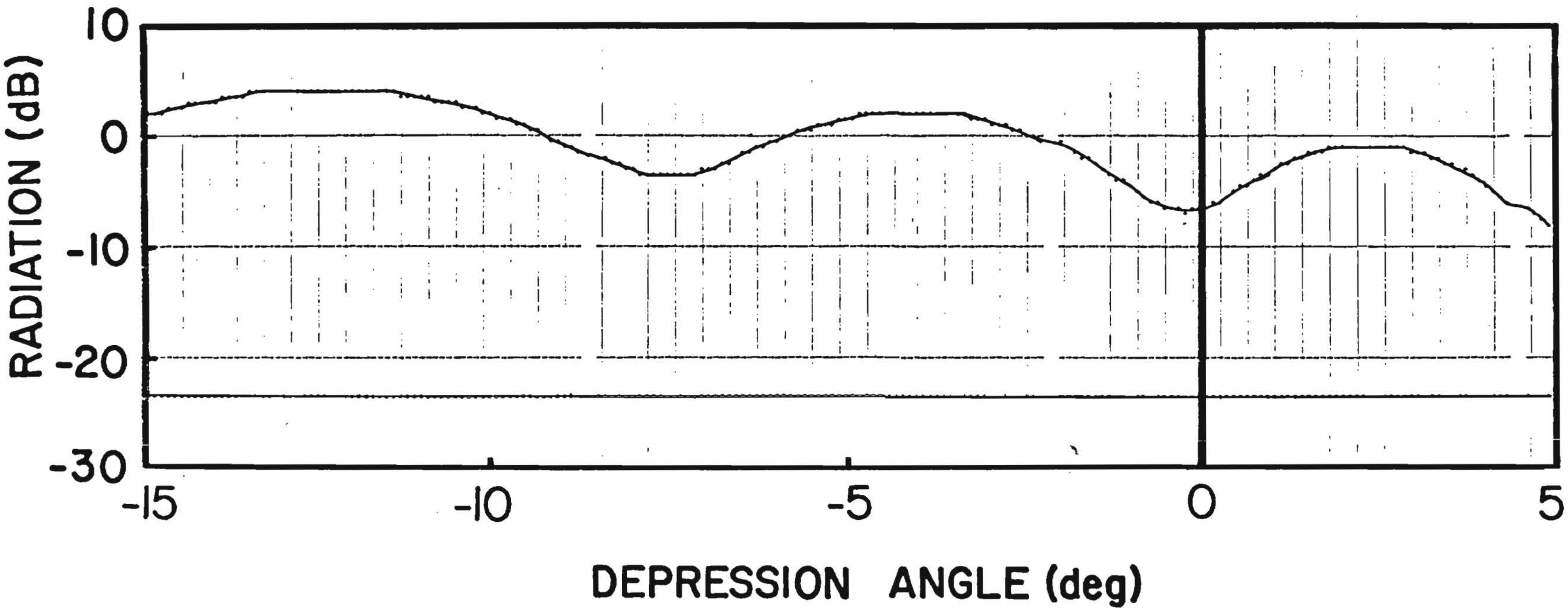


Figure 6. Expanded scale for the data in Figure 5.

alternate model. That is why the impedances that were compared are much lower than the impedance reported for the present configuration with the connected ignition wire. Without the ignition wire connected the resistance is low and the reactance is negative; with the wire connected, the resistance is high and the reactance positive. However, the impedance of the alternate configuration does not match 50 ohms significantly better than does the impedance for the present configuration. Its transmission loss is about 4½ dB. Furthermore, its efficiency is about 73%, even lower than that of the present configuration.

The only other realistic significant change in configuration appeared to be connecting the gas tank to the receiver can and burn tube. Since the connecting of the burn tube raised the input resistance of the antenna far beyond 50 ohms and the reactance of the antenna far beyond 0, the connection of further metallic bulk to the antenna would carry the impedance values out of any reasonable range. Therefore, this alternative was not investigated.

Two configurations were investigated in order to gain some insight into the characteristics of this configuration, though neither one is a realistic option. The first is made up of the antenna parts alone minus the burn tube. That is, the parasitic metallic parts and the burn tube (which was thought to be parasitic) are deleted. The model for this configuration is shown in Figure 7 (except for the tow cable which is connected in the same place). Its pattern, shown in Figure 8, does not differ much from those of Figure 4, and the impedance changes only slightly to (19, -86)Ω.

In order to investigate the source of the impedance problem, it was decided to model only the half of the antenna that included the receiver can. (Again, this was before it was known that the burn tube was connected.) In order to eliminate the tow-cable side, a mirror image reciever can was connected in place of that side of the antenna as shown in Figure 9. The impedance for this system was (1.8, -47.0)Ω, resulting in a mismatch loss of about 11 dB, again, not as bad as expected. A similar configuration was evaluated without the receiver can pyramids. Only one wire extending to the far corner of the pyramid base was used to represent the receiver can. It yielded an impedance of (3.0, -368)Ω which results in

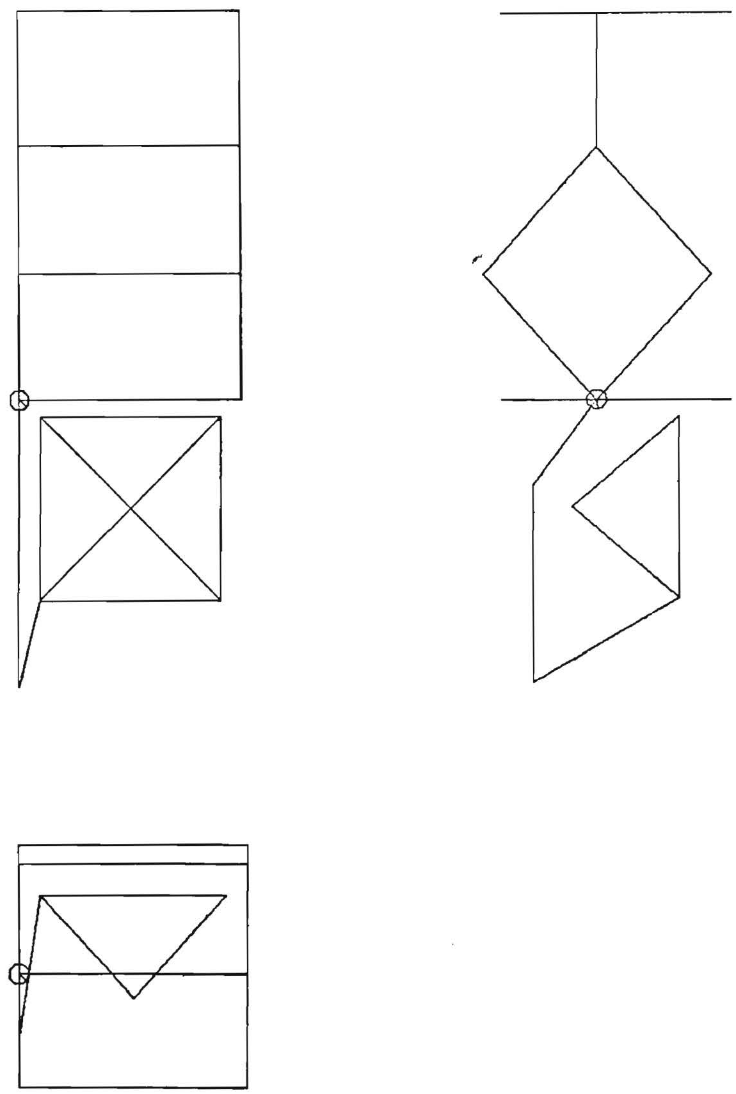


Figure 7. Experimental configuration of fewest components.

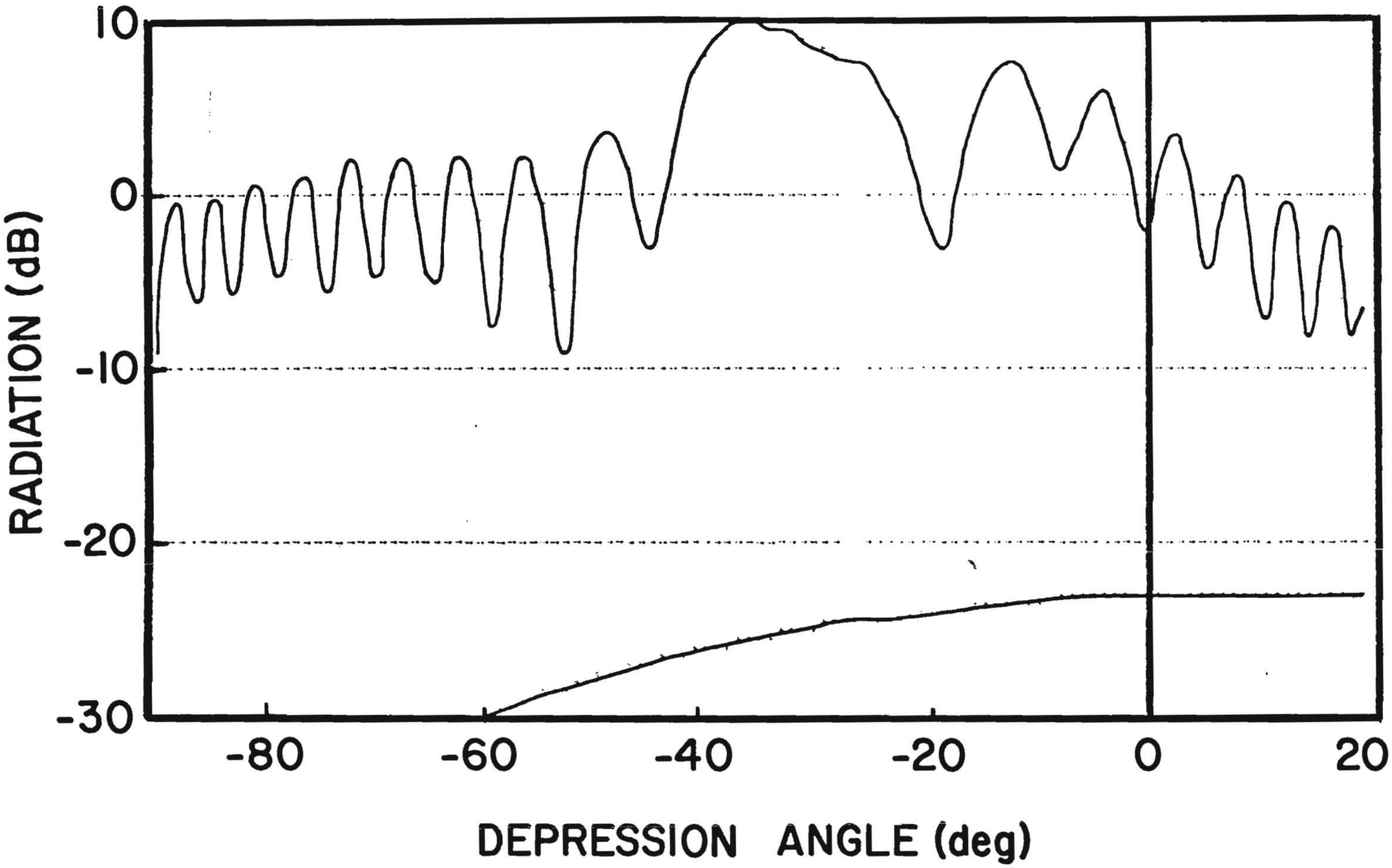


Figure 8. Pattern of the configuration of Figure 7.

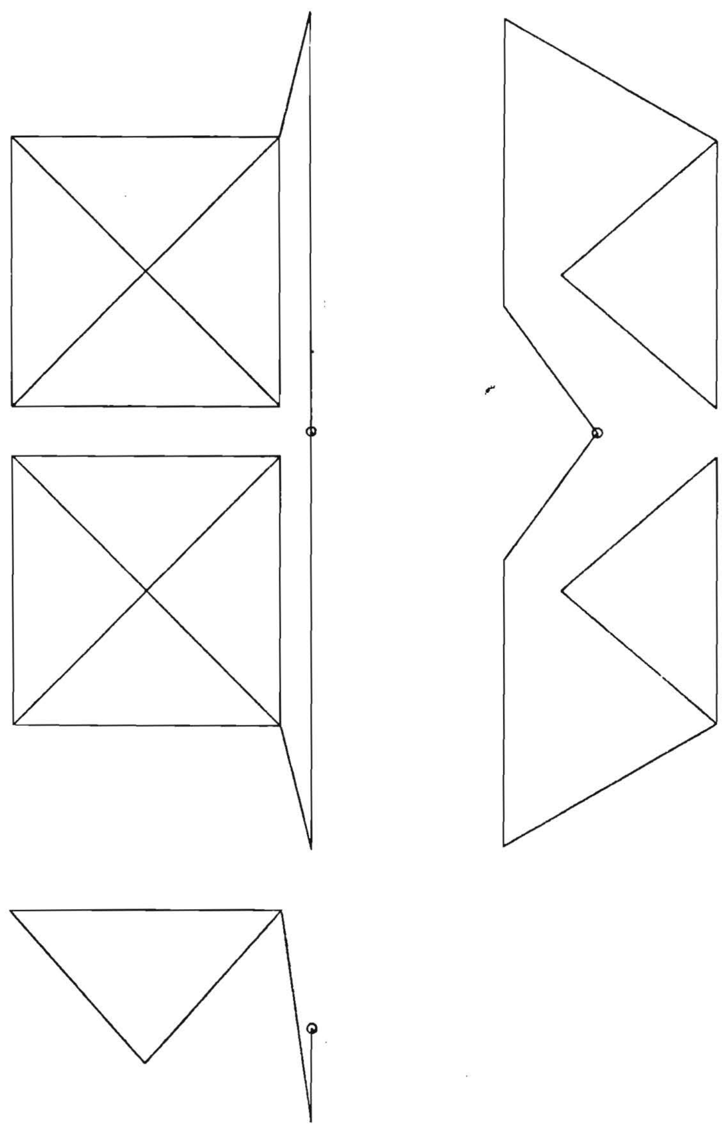


Figure 9. Model for investigating one side of the receive antenna.

a mismatch loss of -24 dB. Clearly the bulk of the receiver can is very important since this antenna had the same length and approximate shape as that of Figure 9, but a much worse impedance.

III. Analysis of Transmit Antenna

Since the receive antenna configuration did not seem to account for the observed loss, a quick analysis was performed on the transmit antenna. This antenna is a commercially produced, electrically small, inductance-fed antenna designed to mount on a ground plane. Since the effect of a ground plane is to produce an image antenna below the ground plane, the ground plane mounted antenna was modeled as an antenna connected to its image as shown in Figure 10. The antenna includes an adjustable lumped capacitance of about 18$\mu\mu$F, which at 72.4 MHz has an reactance of -122 ohms. This lumped reactance was adjusted by trial and error to obtain an impedance match at the feed point. At about -150 ohms, an impedance of (50, -89)Ω was obtained.

Since this is a wire antenna, the thin wire algorithm is directly applicable. Though the wire is not circular in cross section, a radius of .008 inches was used as a reasonable estimate of its size. A conductivity of 58 x 10^6 Mhos/m was used. With a lumped reactance of -150 ohms, the loss due to the mismatch was 2½ dB, but the efficiency of the antenna was only 3%. The low efficiency means that the radiated energy was about -15 dB from the transmitter power, the rest being lost as heat. This loss is reflected in the pattern shown in Figure 11. The pattern is not a full 15 dB down from isotropic because there is about 1½ dB of directivity in this plane.

Of course, the transmit antenna is mounted on the bottom of a Lear jet rather than on a ground plane. The effect of the Lear jet on the transmit antenna performance was not evaluated because Georgia Tech believes that it would not be significant in this case. The fact that the antenna is mounted on a curved surface rather than on a ground plane should not affect the impedance or efficiency measurably, and it should not affect the directivity more than 1 or 2 dB. The presence of the wings, tail, and other aircraft parts can affect the pattern due to scattered signals interfering with the direct signal. In the case of the Lear jet, there are

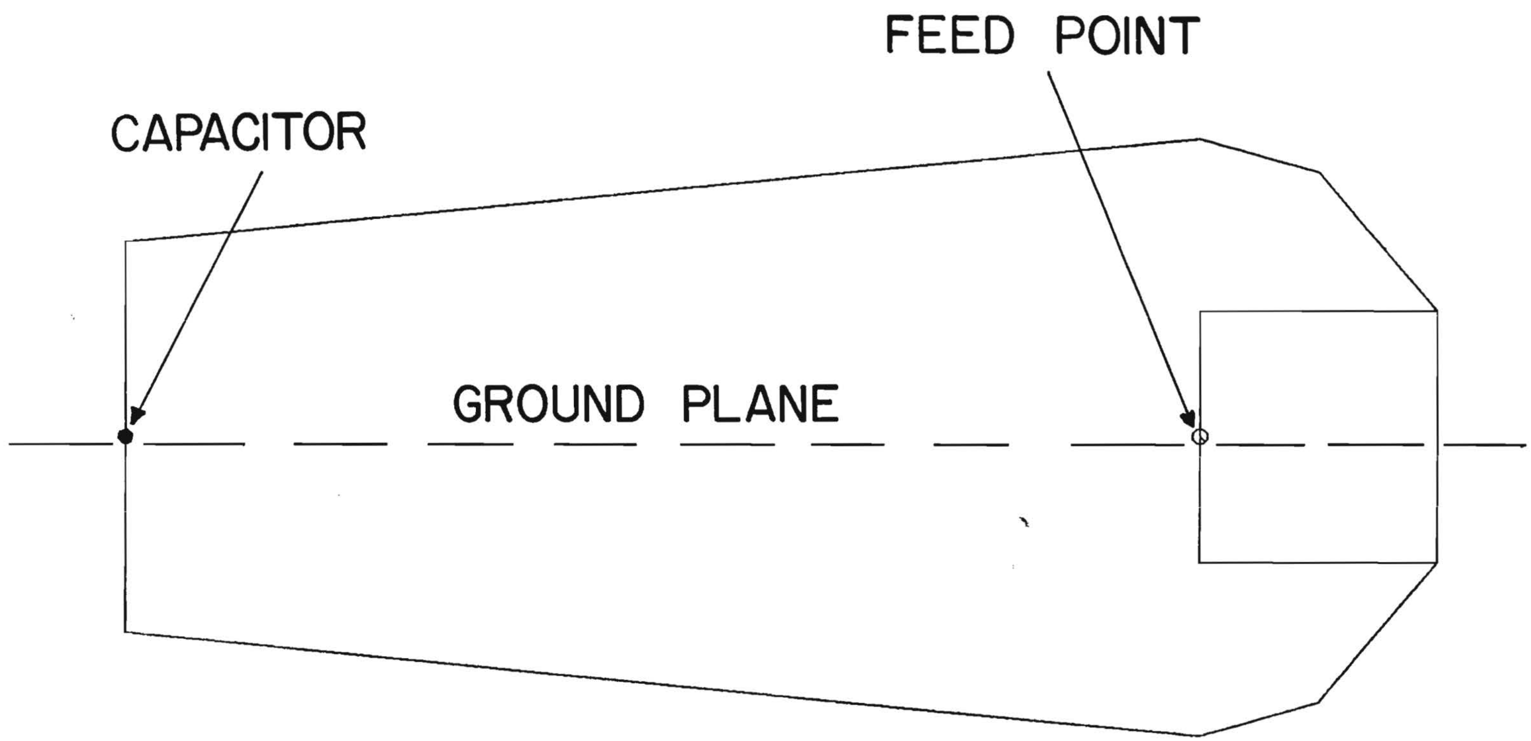


Figure 10. Model of the transmit antenna mounted on a ground plane.

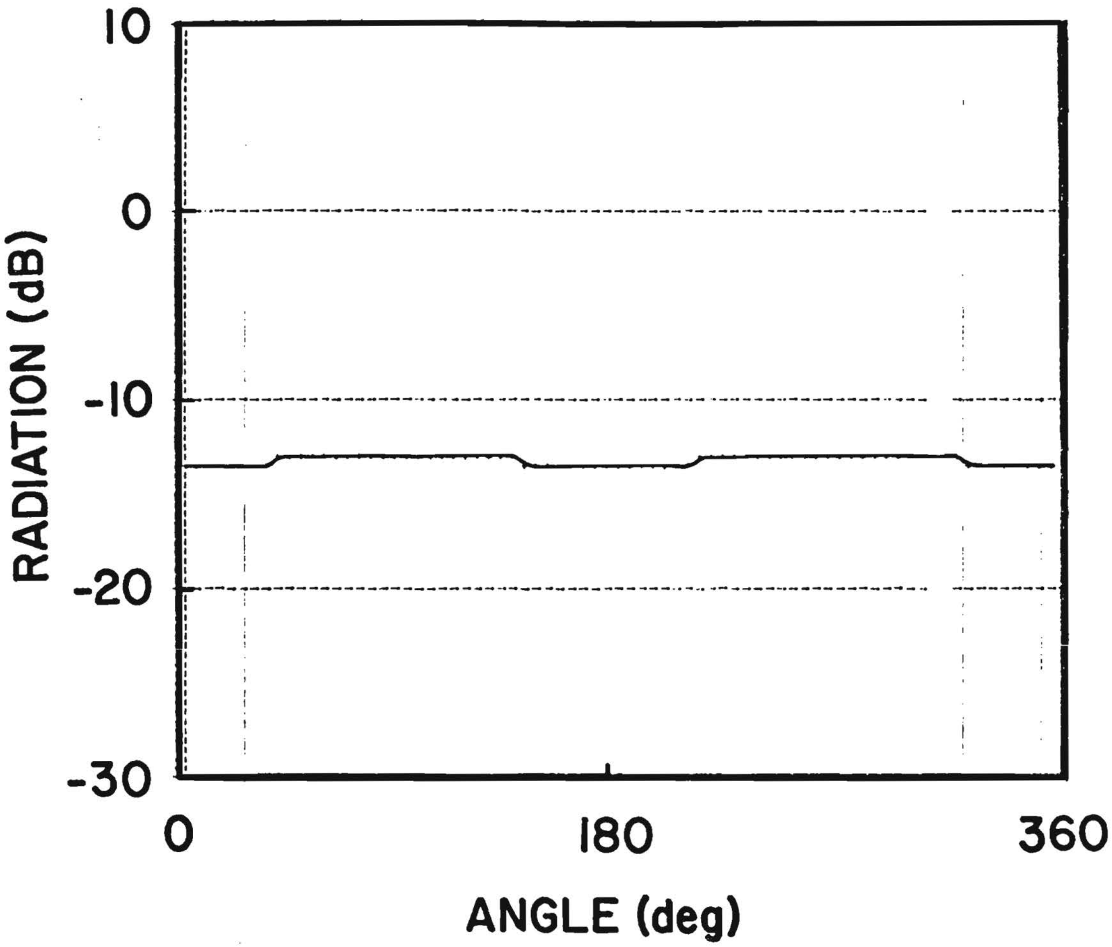


Figure 11. Pattern of the transmit antenna in the plane of the antenna.

no components of the aircraft that can come close to shadowing the antenna, nor are there any surfaces of significant size that can reflect a signal in the direction of the tow target. Thus, it is judged that scattering from aircraft parts could not account for more than 1 or 2 additional dB of pattern variation.

IV. Conclusions

The conclusions that may be drawn from this investigation are summarized in Table 1. The numerical entries that represent the expected signal gain or loss are based on calculations as indicated in the third column. However, the numerical tolerances listed in column 2 are primarily based on experienced judgement. The receive directivity is an exception. Since a variation in directivity of +1 to -6 dB was calculated, ±1 dB was included as calculation uncertainty. In the direction of the aircraft, the directivity was about +2 dBi, but the actual value could be anywhere between the maximum and minimum of these lobes because the pattern could easily shift a few degrees due to inaccuracies in the model of the tow-cable contour, the truncation effect of the Georgia Tech model, or variation of the flight attitude of the target.

The most significant source of loss is inefficiency in the transmit antenna. This was due to the resistivity of the metallic antenna element and did not include effects of the radome or encapsulation material. The latter effects are not expected to be very important, but the metal alloy could be important. The resistivity of copper was used in this calculation and if the alloy is significantly more resistive, this loss could be significantly higher.

The expected loss from the combined effects is about 24 dB, but it could be as much as 41 dB. It appears very unlikely that 41 dB of loss could be attributed to this antenna link because it would require that all inaccuracies be on the same side of the estimate. Thus, the final conclusion of this investigation is that it has not accounted for the total loss observed. However, it has accounted for much of the loss and the loss that remains should be easier to find.

Georgia Tech has several recommendations regarding the improvement of the loss parameters listed in the table. The first recommendation, with

TABLE 1

SUMMARY OF EXPECTED LOSSES

Item	Loss (dB) Expected	Error Range	Approach
Receive			
Mismatch	-7	+2, -3	Calculation (MOM)
Directivity	+2	+2, -7	Calculation (MOM)
Efficiency	-1	±1	Calculations (MOM) with conductivity estimate
Transmit			
Mismatch	-3	±1	Calculations (MOM)
Directivity	+1	±0	Calculations (MOM)
Efficiency	-15	±3	Calculations (MOM) with conductivity estimate
Aircraft Effects	-1	±2	Judgement
Total	-24	+11, -17	

regard to the mismatch between the receive antenna and the receiver, is to measure the input impedance of both antennas. Measurement of the antenna impedance would verify the calculations, whereas measurement of the receiver impedance would show whether the assumption of 50 ohms was correct. Only one possibility to improve this mismatch has suggested itself, and that is to isolate the burn tube at RF frequencies. This should be easily achievable with an inductance, but it is not strongly recommended because the improvement would only be on the order of 4 dB.

The impedance of the transmit antenna was found be very sensitive to the value of the capacitor. The impedance of this antenna as installed should be measured, and it would be wise to measure the impedance of the transmitter also. The impedance measurement of the antenna is particularly important because Georgia Tech could not model it precisely as it is configured. That is because the antenna has a bottom plate which mounts against the ground plane, but which cannot be considered as part of the ground plane. There is an insulating pad between this plate and the mounting surface which allows the plate to contact the mounting surface only through the mounting screws. It seems reasonable to assume that the vendor would not include this insulating layer if it seriously degraded the antenna performance, but it is also reasonable to check that assumption by making the recommended impedance measurements.

The efficiency should be further checked because Georgia Tech used an estimate of the conductivity of the alloy. The efficiency (or the antenna gain, which includes the efficiency), should be obtainable from the vendor. If not, a better estimate of the conductivity should be obtained and the calculation repeated if necessary.

Georgia Tech has a final recommendation that is technically unrelated to this investigation. It is recommended that Hayes investigate the effects of static electricity build-up on the tow-cable antenna and the degree to which such a build-up might occur. It would appear that a conductor as long as this tow cable may be particularly susceptible to a build-up of static electrical charges ("p-static"), which can give rise to corona discharges which may produce extreme electrical noise.